

# **Processes At Sloping Boundaries in The Coastal Ocean**

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## **LONG-TERM GOALS**

To understand and parameterize interior and near-boundary mixing processes.

To understand the dynamical processes occurring in the surface layer of the ocean and parameterize them in ocean models.

To understand the physical oceanography of semi-enclosed seas.

## **OBJECTIVES**

A current objective is to exploit Juan de Fuca Strait as a natural laboratory for the study of rotating stratified shear flows with sloping lateral boundaries. In particular I would like to understand and quantify vertical and lateral momentum transfer, the causes and role of cross-strait secondary circulation, and the comparative importance, magnitude and parameterization of internal and near-boundary mixing.

In the surface mixed layer I would like to understand and parameterize the effects of processes currently omitted from models.

For semi-enclosed seas I seek the key physics that controls the overall behavior.

## **APPROACH**

For the last four summers we have conducted observational studies in Juan de Fuca Strait involving one or more bottom-mounted 300 kHz broadband ADCPs, temperature and conductivity moorings, and CTD, turbidity and microstructure sections. Senior Research Associate Richard Dewey assumes much of the responsibility for this, with assistance from postdoctoral fellow Kate Stansfield. Graduate students Michael Ott and Keir Colbo are also involved and will be basing their Ph.D. theses on various aspects of the work. Graduate student Elina Tragou evaluated the lateral eddy momentum flux in a tidal channel. Ship time has been provided by Canadian funding.

I have also returned recently to conceptual models of the internal wave field, in particular examining reasons why the near-inertial band should be different from the rest of the spectrum.

For surface mixed layer investigations, graduate student Konstantin Zahariev used numerical models to investigate the effects of internal wave heaving of the base of the layer. In conjunction with Ming Li and David Farmer, I have investigated simple analytical models relating bubble size spectra to the dissipation rate in breaking waves.

Graduate student Elina Tragou investigated the overall forcing and dynamics of the Red Sea using simple models and available oceanographic and atmospheric data sets.

## **WORK COMPLETED**

In 1999 we obtained a five week data set at the sloping north side of Juan de Fuca Strait, using a triangular array of three ADCPs (one a prototype model with one vertical beam and three inclined beams) and a linear array of three thermistor chains. The project is collaborative with Dr. Parker MacCready of the University of Washington and should tell us about secondary cross-strait mean flows and also allow us to discriminate between internal wave motions, which can cause mixing, and vortical modes which can stir fluid away from the boundary. Analysis of data from 1998 has provided ratios of clockwise to anticlockwise energy and vertical to horizontal motion as functions of frequency. These provide a partial indication of the split between internal waves and vortical modes, but the situation will become clearer with the array data.

A study of Thorpe scales as a measure of vertical mixing in an estuarine environment has been completed. We have also completed a study of the lateral eddy momentum flux in a tidal channel.

I have proposed that a criterion for defining a “near-inertial” band for the oceanic internal wave field comes from considering inertial waves generated at their turning latitude and then propagating equatorward.

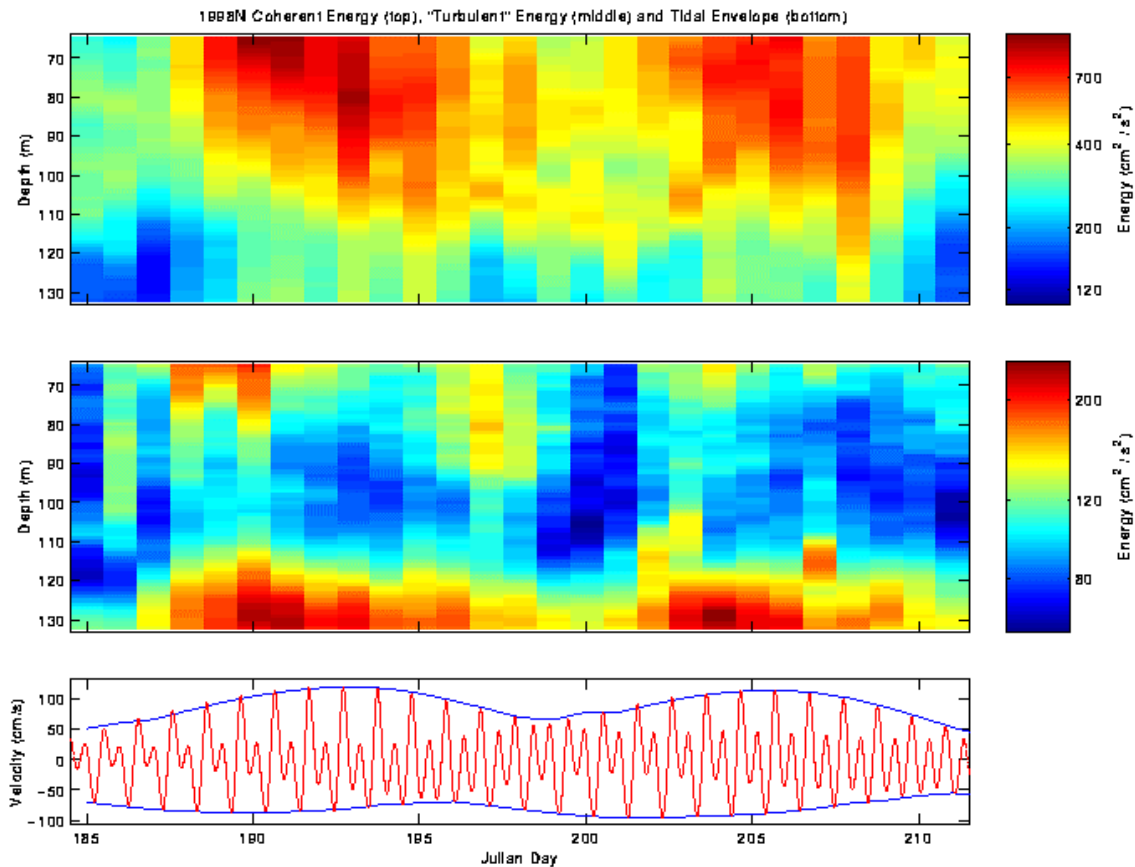
In collaboration with Ming Li and David Farmer I have proposed various simple models for the bubble size spectrum in breaking waves and for its evolution in response to buoyancy forces and dissolution.

## **RESULTS**

Keir Colbo and Richard Dewey have found a clear spring-neap modulation of internal wave activity, and higher frequency fluctuations, in Juan de Fuca Strait. (Keir Colbo received an AGU graduate student award for his presentation of this at the 1998 fall meeting.)

Analysis of good CTD profiles suggests that vertical mixing in regions such as this can be obtained with reasonable reliability from the Thorpe scale as this is not greatly affected by the small, unreliably determined, overturns. We have also analyzed the probability distribution of Thorpe displacements and compared it with a simple, novel, analytical model.

Analysis of the lateral eddy momentum flux in a tidal channel has shown that it may be possible to determine a lateral eddy viscosity parameterization for use in models, though considerable averaging over an ensemble of tidal cycles is required because of lack of a spectral gap in the frequency domain.



**1. A discretization of the ADCP kinetic energy field into high frequency coherent motions (internal waves and vortical modes) [top], and turbulent energy ( $\omega > N$ ) [middle], with the observed barotropic tide and tidal envelope [bottom]. Water depth is 135 m.**

A simple analysis of inertial waves shows that by the time they first encounter the sea floor they have a frequency that exceeds the local inertial frequency by a calculable amount that is about  $0.1f$  at mid-latitudes. In this narrow band the wave propagation should be primarily downward (as shown by data) and have a vertical wavenumber spectrum that is unaffected by bottom reflection and scattering. This suggests a novel approach to internal wave theory, assigning more importance to near-inertial waves and to bottom scattering.

In a contribution to the physics of the surface mixed layer, Ming Li, David Farmer and I have proposed a dimensional argument leading to a predicted  $-10/3$  power law for the bubble size spectrum in turbulence. Weaknesses in the argument lead us also to suggest as an alternative that the size spectrum reflects the intermittency of the turbulence. We show that the effect of dissolution is to flatten the size spectrum at small scales, while buoyancy tends to steepen the average spectrum observed. These effects lead to a knee in the spectrum at a radius of about 100 microns, consistent with some observations.

## IMPACT/APPLICATIONS

Our results should clarify the comparative importance for estuarine circulation of internal vertical friction and lateral friction at the sloping sides. It will also provide a better understanding of the

contribution to cross-strait secondary flows of internal Ekman layers, converging bottom Ekman layers on the sloping sides and the density-driven flow of boundary-mixed fluid. We also hope to learn about the relative importance of internal waves and vortical modes for mixing and stirring in an estuarine environment. Refined procedures for the evaluation of Thorpe scales from CTD profiles may lead to more reliable determination of mixing rates in estuaries and on the continental shelf. Overall, we hope that results obtained in Juan de Fuca Strait will lead to understanding and parameterizations of general relevance.

A specification of what determines the “near-inertial” band may help to focus internal wave studies.

Simple models of bubbles in the upper ocean will help focus research on what we do not know.

## **TRANSITIONS**

We are collaborating with Professor Parker MacCready and others at the University of Washington.

## **RELATED PROJECTS**

The projects described above are also supported by Canadian funding agencies. Other projects underway include an analysis of long-term sea level and other data from the vicinity of the Strait of Gibraltar in a continued exploration of the maximal or submaximal nature of the exchange.

## **PUBLICATIONS**

Li, M. and Garrett, C. 1998: The relationship between oil droplet sizes and upper ocean turbulence. *Marine Pollution Bulletin*, 36, 961-970.

Tragou, E., Garrett, C., Outerbridge, R. and Gilman, C. 1999: The heat and water budgets for the Red Sea. *Journal of Physical Oceanography* (in press).

Garrett, C. 1999: What is the near-inertial band and why is it different from the rest of the internal wave continuum? *Proceedings of the Eleventh ‘Aha Huliko’a Hawaiian Winter Workshop* (in press).

Garrett, C., Li, M. and Farmer, D. 1999: A note on the connection between bubble size spectra and energy dissipation rates in the upper ocean. *Journal of Physical Oceanography* (in press).

Colbo, K. and Li, M. 1999: Parameterizing particle dispersion in Langmuir circulation. *Journal of Geophysical Research* (in press).

Stansfield, K., Garrett, C. and Dewey, R. 1999: Calculating Thorpe scales and vertical mixing from CTD data, with application to Juan de Fuca Strait. *Journal of Physical Oceanography* (submitted).

Tragou, E., Garrett, C. and Dewey, R. 1999: Measurements of lateral eddy momentum flux in a tidal channel. *Journal of Physical Oceanography* (submitted).

Zahariev, K. 1999: The effect of isopycnal heaving on the temperature and thickness of the surface mixed layer. *Journal of Physical Oceanography* (submitted).